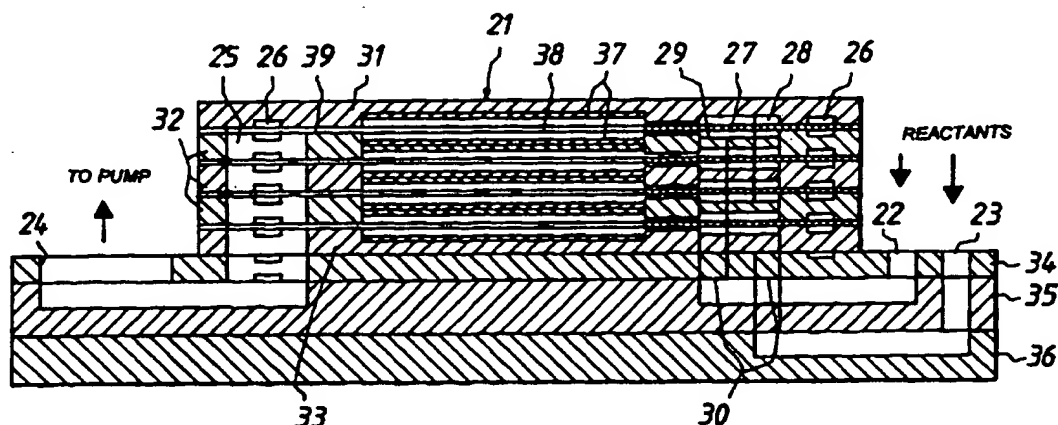




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> : <b>C23C 16/44, 16/00, C30B 25/02</b>	<b>A1</b>	(11) International Publication Number: <b>WO 96/17107</b> (43) International Publication Date: <b>6 June 1996 (06.06.96)</b>
<p>(21) International Application Number: <b>PCT/FI95/00658</b></p> <p>(22) International Filing Date: <b>28 November 1995 (28.11.95)</b></p> <p>(30) Priority Data: <b>945611 28 November 1994 (28.11.94) FI</b></p> <p>(71) Applicant (for all designated States except US): <b>MIKROKEMIA OY [FI/FI]; PL 45, FIN-02151 Espoo (FI).</b></p> <p>(72) Inventors; and (75) Inventors/Applicants (for US only): <b>SUNTOLA, Tuomo [FI/FI]; Vasamatie 25, FIN-02630 Espoo (FI). LINDFORS, Sven [FI/FI]; Nuottamiehentie 8, FIN-02230 Espoo (FI).</b></p> <p>(74) Agents: <b>LAINNE, Seppo et al.; Seppo Laine Oy, Lönnrotinkatu 19 A, FIN-00120 Helsinki (FI).</b></p>	<p>(81) Designated States: <b>AL, AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TT, UA, UG, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, LS, MW, SD, SZ, UG).</b></p> <p><b>Published</b> <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i></p>	

(54) Title: METHOD AND APPARATUS FOR GROWING THIN FILMS



## (57) Abstract

The invention relates to a method and apparatus for growing a thin film onto a substrate, in which method a substrate placed in a reaction space (21) is subjected to alternately repeated surface reactions of at least two vapor-phase reactants for the purpose of forming a thin film. According to the method, said reactants are fed in the form of vapor-phase pulses repeatedly and alternately, each reactant separately from its own source, into said reaction space (21), and said vapor-phase reactants are brought to react with the surface of the substrate for the purpose of forming a solid-state thin film compound on said substrate. According to the invention, the gas volume of said reaction space is evacuated by means of a vacuum pump essentially totally between two successive vapor-phase reactant pulses. By virtue of transporting the different starting material species at different times through the apparatus effectively isolates the starting materials from each other thus preventing their premature mutual reactions.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	GB	United Kingdom	MR	Mauritania
AU	Australia	GE	Georgia	MW	Malawi
BB	Barbados	GN	Guinea	NE	Niger
BE	Belgium	GR	Greece	NL	Netherlands
BF	Burkina Faso	HU	Hungary	NO	Norway
BG	Bulgaria	IE	Ireland	NZ	New Zealand
BJ	Benin	IT	Italy	PL	Poland
BR	Brazil	JP	Japan	PT	Portugal
BY	Belarus	KE	Kenya	RO	Romania
CA	Canada	KG	Kyrgyzstan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo	KR	Republic of Korea	SE	Sweden
CH	Switzerland	KZ	Kazakhstan	SI	Slovenia
CI	Côte d'Ivoire	LI	Liechtenstein	SK	Slovakia
CM	Cameroon	LK	Sri Lanka	SN	Senegal
CN	China	LU	Luxembourg	TD	Chad
CS	Czechoslovakia	LV	Latvia	TG	Togo
CZ	Czech Republic	MC	Monaco	TJ	Tajikistan
DE	Germany	MD	Republic of Moldova	TT	Trinidad and Tobago
DK	Denmark	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	US	United States of America
FI	Finland	MN	Mongolia	UZ	Uzbekistan
FR	France			VN	Viet Nam
GA	Gabon				

### Method and apparatus for growing thin films

The present invention relates to a method according to the preamble of claim 1 for growing thin films on a substrate.

5

In the present method, the substrate is typically located in a reaction space, wherein it is in accordance with the Atomic Layer Epitaxy (ALE) method is subjected to alternately repeated surface reactions of at least two different reactants.

According to the present method, the reactants are admitted repetitively and alternately each reactant at a time from its own source in the form of vapor-phase pulses into the reaction space. Here, the vapor-phase reactants are allowed to react with the substrate surface for the purpose of forming a solid-state thin film on the substrate.

While the method is most appropriately suited for producing so-called compound thin films using as the reactants such starting materials that contain component elements of the desired compound thin-film, it may also be applied to growing elemental thin films. Of compound films typically used in the art, reference can be made to ZnS films employed in electroluminescent displays, whereby such films are grown on a glass substrate using zinc sulfide and hydrogen sulfide as the reactants in the growth process. Of elemental thin films, reference can be made to silicon thin films.

The invention also concerns an apparatus according to the preamble of claim 15 suited for producing thin films.

The apparatus comprises a reaction space into which the substrate can be placed, and at least two reactant sources from which the reactants used in the thin-film growth process can be fed in the form of vapor-phase pulses into the reaction space. The sources are connected to the reaction space via reactant inflow channels, and outflow channels are connected to the reaction space for removing

30

the gaseous reaction products of the thin-film growth process as well as the excess reactants in vapor phase.

Conventionally, thin-films are grown using vacuum evaporation deposition, the  
5 Molecular Beam Epitaxy (MBE) and other vacuum deposition methods, different  
variants of the Chemical Vapor Deposition (CVD) method (including low-pressure  
and metal-organic CVD and plasma-enhanced CVD), or alternatively, the above-  
described deposition method of alternately repeated surface reactions called the  
Atomic Layer Epitaxy (ALE) method. In the MBE and CVD methods, besides  
10 other process variables, the thin-film growth rate is also affected by the concentra-  
tions of the starting material inflows. To achieve a uniform thickness of the layers  
deposited by the first category of conventional methods, the concentrations and  
reactivities of starting materials must hence be carefully kept constant all over the  
substrate area. If the starting materials are allowed to mix with each other prior to  
15 reaching the substrate surface as is the case in the CVD method, for instance, a  
chance of their premature mutual reaction arises. Then, the risk of microparticle  
formation already within the inflow channels of the gaseous reactants is imminent.  
Such microparticles have a deteriorating effect on the quality of the thin film  
growth. Therefore, the possibility of premature reactions in MBE and CVD  
20 reactors is avoided by heating the starting materials no earlier than at the substrate  
surfaces. In addition to heating, the desired reaction can be initiated using, e.g., a  
plasma or other similar activating means.

In the MBE and CVD processes, the growth of thin films is primarily adjusted by  
25 controlling the inflow rates of starting materials impinging on the substrate. By  
contrast, the ALE process is based on allowing the substrate surface qualities  
rather than the starting material concentrations or flow variables to control the  
deposition rate. The only prerequisite in the ALE process is that the starting  
material is available in sufficient concentration for thin-film formation on all sides  
30 of the substrate.

The ALE method is described in the FI patent publications 52,359 and 57,975 and in the US patent publications 4,058,430 and 4,389,973, in which also some apparatus embodiments suited to implement this method are disclosed. Apparatus constructions for growing thin films are also to be found in the following publications: Material Science Reports 4(7) (1989), p. 261, and Tyhjiötekniikka (Finnish publication for vacuum techniques), ISBN 951-794-422-5, pp. 253-261.

In the ALE growth method, atoms or molecules are arranged to sweep over the substrates thus continuously impinging on their surface so that a fully saturated molecular layer is formed thereon. According to the conventional techniques known from the FI patent publication No. 57,975, the saturation step is followed by an inert gas pulse forming a diffusion barrier which sweeps away the excess starting material and the gaseous reaction products from above the substrate. The successive pulses of different starting materials and of diffusion barriers of an inert gas separating the former accomplish the growth of the thin film at a rate controlled by the surface chemistry properties of the different materials. Such a reactor is called a "traveling-wave" reactor. For the function of the process it is irrelevant whether the gases or the substrates are moved, but rather, it is imperative that the different starting materials of the successive reaction steps are separated from each other and arranged to impinge on the substrate successively.

Most vacuum evaporators operate on the so-called "single-shot" principle. Herein, a vaporized atom or molecule species can impinge on the substrate only once. If no reaction of the species with the substrate surface occurs, the species is bounced or re-vaporized so as to hit the apparatus walls or the inlet to the vacuum pump undergoing condensation therein. In hot-wall reactors, an atom or molecule species impinging on the reactor wall or the substrate may become re-vaporized, whereby advantageous conditions are created for repeated impingements of the species on the substrate. When applied to ALE reactors, this "multi-shot" principle can provide, i.e., improved material utilization efficiency.

In conventional ALE apparatuses, a characterizing property is that the different starting materials of the reaction are understood to be isolated from each other by means of a diffusion wall formed by an inert gas zone traveling between two successive pulses of starting materials (cf. above-cited FI patent publication No. 57,975 and the corresponding US Pat. No. 4,389,973). The length of the inert gas zone acting as the downstream flowing diffusion wall is such that only approx. one millionth of the reactant gas molecules have a sufficient diffusion velocity to travel under the prevailing conditions in the counterflow direction to a distance greater than the thickness of the isolating diffusion wall employed in the method.

However, notwithstanding the high reliability of the above-described arrangement, it has some disadvantages. For instance, the cross sections and shapes of piping in practical reactor constructions vary between, e.g., the infeed manifold and the substrates, whereby the thickness and shape of the diffusion wall become difficult to control and the starting materials may become carried over into contact with each other. The diffusion wall may also become destroyed in the nozzles feeding the vapor-phase reactant to the substrates, in gas mixers or at other discontinuity points of the piping. The laminarity of gas inflow may also become disturbed by a too tight bend in the piping.

Intermixing of starting materials in flow systems cannot be prevented simply by keeping the gas volumes apart from each other, because mixing may also occur due to adherence of molecules from a starting material pulse on the apparatus walls or discontinuities thereof, wherefrom the molecules may then gain access with the molecules of the successive starting material pulse.

It is an object of the present invention to overcome the drawbacks of conventional technology and to provide an entirely novel arrangement for growing thin films.

The goal of the invention is achieved by virtue of admitting vapor-phase pulses of the starting material reactants into the ALE reactor so that each starting material

pulse is individually driven through the piping and reaction space of the apparatus isolated from the other pulses. According to the invention, this concept is implemented by means of purging the gas volume of the reaction space containing reactive gas between two successive vapor-phase pulses essentially entirely which means a purging efficiency of at least 99 %, preferably 99.99 %. Thence, all the reacting gas, which in practice refers to the entire gas volume filled with the vapor-phase reactant, is purged from the reaction space between the successive pulses. The reactant pulses of different starting materials will thus remain isolated from each other, whereby no mixing of the reactants can occur

10

In the apparatus suited to implement the method, the outflow channels are connected to a pump capable of evacuating the reaction space to a vacuum, whereby the pump capacity is dimensioned sufficiently high to permit full evacuation of a volumetric amount of gas corresponding to the gas volume of the reaction space out from the reaction space during the interval between two successive vapor-phase reactant pulses. Accordingly the pump must have a volumetric flow capacity per time unit, advantageously over the interval between two successive vapor-phase reactant pulses, that is greater than the gas volume of the reaction space.

15

More specifically the method according to the invention is principally characterized by what is stated in the characterizing part of claim 1.

20

Furthermore, the apparatus according to the invention is principally characterized by what is stated in the characterizing part of claim 15.

25

In the context of the present invention, the term "evacuation" is used generally referring to the removal of reactant residues in the vapor phase. The evacuation of the reaction space can be accomplished by purging the gas volume of the apparatus by means of at least one pumping cycle capable of lowering the internal pressure in the apparatus to a sufficiently high vacuum. When required, the appa-

30

ratus may be simultaneously filled with an inactive gas which promotes the purging of the reactant residues from the reaction space.

5 In the present context, the term "inactive" gas is used to refer to a gas which is admitted into the reaction space and is capable of preventing undesired reactions related to the reactants and the substrate, respectively. Such reactions include the reactions of the reactants and the substrate with possible impurities, for instance. The inactive gas also serves for preventing reactions between the substances of the different reactant groups in, e.g., the inflow piping. In the method according to the  
10 invention, the inactive gas is also used advantageously as the carrier gas of the vapor-phase pulses of the reactants. According to a preferred embodiment, in which the reactants of the different reactant groups are admitted via separate inlet manifolds into the reaction space, the vapor-phase reactant pulse is admitted from one inflow channel while the inactive gas is admitted from another inflow channel  
15 thus preventing admitted reactant from entering the inflow channel of another reactant. Of inactive gases suited for use in the method, reference can be made to inert gases such as nitrogen gas and noble gases, e.g., argon. The inactive gas may also be an inherently reactive gas such as hydrogen gas serving to prevent undesirable reactions (e.g., oxidization reactions) from occurring on the substrate surface.

20 According to the invention, the term "reaction space" includes both the space in which the substrate is located and in which the vapor-phase reactants are allowed to react with the substrate in order to grow thin films (namely, the reaction chamber) as well as the gas inflow/outflow channels communicating immediately  
25 with the reaction chamber, said channels serving for admitting the reactants into the reaction chamber (inflow channels) or removing the gaseous reaction products of the thin-film growth process and excess reactants from the reaction chamber (outflow channels). According to the construction of the embodiment, the number of the inflow and outflow channels, respectively, can be varied from one upward.  
30 According to the invention, the reaction space is the entire volume to be evacuated between two successive vapor-phase pulses.



In the present context, the term "reactant" refers to a vaporizable material capable of reacting with the substrate surface. In the ALE method, reactants belonging in two different groups are conventionally employed. The reactants may be solids, liquids or gases. The term "metallic reactants" is used of metallic compounds which may even be elemental metals. Suitable metallic reactants are the halogenides of metals including chlorides and bromides, for instance, and metal-organic compounds such as the thd complex compounds. As examples of metallic reactants may be mentioned Zn, ZnCl<sub>2</sub>, TiCl<sub>4</sub>, Ca(thd)<sub>2</sub>, (CH<sub>3</sub>)<sub>3</sub>Al and Cp<sub>2</sub>Mg. The term "nonmetallic reactants" is used for compounds and elements capable of reacting with metallic compounds. The latter group is appropriately represented by water, sulfur, hydrogen sulfide and ammonia.

Herein, the term "substrate surface" is used to denote that top surface of the substrate on which the vapor-phase reactant flowing into the reaction chamber first impinges. In practice, said surface during the first cycle of the thin-film growing process is constituted by the surface of the substrate such as glass, for instance; during the second cycle the surface is constituted by the layer comprising the solid-state reaction product which is deposited by the reaction between the reactants and is adhered to the substrate, etc.

As mentioned above, in a practical embodiment the vapor-phase reactants are conventionally driven by a carrier gas flow into the reaction chamber and further through it. Therefore, the vapor-phase reactant obtained from a source is mixed with the inert gas flow at some point of the apparatus. In the present embodiment, the term "reaction space gas flow channels" also includes that section of the reactant inflow pipes which is located after the control valves of the inactive gas flow.

A characterizing property of the present invention is that the different starting materials are not allowed to flow simultaneously in the piping or reactor (reaction space), but rather, the piping and reaction space are evacuated from the contents of the preceding vapor-phase pulse prior to the admission of the next vapor-phase

pulse. Advantageously, the interval between the successive pulses is kept so long as to permit the evacuation of the reaction space using at least a double or triple purging gas volume during the interval between the pulses. To achieve maximally efficient evacuation of reactant residues, the reaction space is purged with an  
5 inactive gas during the interval between the reactant pulses and the total volume of gas evacuated from the reaction space during the interval between the reactant pulses amounts to at least 2 - 10 times the volume of the reaction space. A design target value of less than 1 %, advantageously less than 1 ‰, of residual components of the preceding vapor-phase reactant pulse remaining at the infeed of the  
10 next pulse can be set for the evacuation efficiency. Operation according to the invention can easily reach a situation in which the reaction space is purged to less than 1 ppm of reactant residues from the preceding pulse.

According to the present method, evacuation is most advantageously implemented  
15 by connecting the reaction space to a pump whose volumetric capacity during the interval between two successive vapor-phase reactant pulses is appreciably greater than the gas volume of the reaction space. As the interval between two successive reactant gas pulses typically is in the order of 1 s, this requirement can be met by connecting such a pump to the reaction space that has a capacity sufficient to  
20 evacuate during said interval a volumetric amount of gas which is advantageously at least 2 - 3 times, and particularly advantageously 4 - 10 times the volume of the reaction space.

The invention can be implemented using any suitable pump capable of establishing a sufficient vacuum in the reaction space and having a sufficient capacity.  
25 Examples of suitable pump types are: rotary vacuum pump, Roots' blower and turbo pump.

To achieve efficient evacuation, the apparatus according to the invention has a  
30 design characterized by minimized volumes and piping cross sections implemented in a construction with minimized number of seams. The piping layout aims to

avoid any structures which could disturb the laminarity of the flow pattern or act as difficult-to-purge gas pockets.

In conventional equipment constructions the above-described goals are difficult to achieve, since gas volumes in the equipment are relatively large in relation to the volume occupied by the products and the gas flow occur via complicated paths. Obviously, a mere diffusion wall cannot purge all gas pockets contained therein. The problems are accentuated in equipment designed for simultaneous thin film growth on multiple substrates.

The present invention discloses a plurality of special properties contributing to the minimization of apparatus gas volume and the formation tendency of spalling films (microparticles). Simultaneously, the invention provides a particularly advantageous embodiment of an apparatus suited for simultaneous deposition of thin films on two or more substrates.

An advantageous approach to reduce equipment contamination is to feed each reactant group via a separate inflow channel directly into the reaction chamber. Preferably, the reactant is allowed to become mixed with a carrier gas flow entering from the inflow channel of another reactant group prior to contacting the reactant with the substrate. The purpose of such mixing is to homogenize the gas flow passing over the substrate.

The above-described embodiment is particularly well suited for thin-film growth processes using at least two compound component reactants. The exit ends of the inflow channels of the different reactant groups, later in the text called the reactant "infeed openings", are adapted to exit into the reaction chamber, close to the substrates of the thin film structures. Between the infeed openings is herein disposed a baffle which prevents the reactant inflow from one infeed opening from entering directly the infeed opening of another reactant belonging to a different reactant group. To eliminate the risk of reactant contamination, a carrier gas flow is hereby

particularly advantageously driven through that inflow channel or channels which is/are currently not used for the infeed of a reactant. Preferably, the reactant infeed openings are disposed on the opposite sides of the baffle and the reactant inflows are directed perpendicularly against the baffle, whereby the gas flow can be spread  
5 into an essentially planar flow producing a "flattened" flow pattern. The carrier gas flow and the vapor-phase reactant flow entering from the opposite directions, respectively, that are flattened by hitting the baffle are combined prior to taking their mixed flow into contact with the substrate. It has been found that the inter-  
10 mixing of different species by diffusion is extremely efficient between the flattened gas flows resulting in excellent uniformity of the gas flow taken to the substrate.

According to an alternative embodiment, the gas volume of the apparatus is minimized by designing those gas flow channels which communicate with the  
15 reaction chamber to have a narrow, oblong cross section in order to minimize the volume of the reaction space. Hence, the gas flow channels have a "flat" shape capable of producing a similar flattened gas flow pattern as in the arrangement of the above-described embodiment.

20 Typically, the flat gas flow channel according to the invention has a cross section with a width (orthogonal to the flow direction of the gas pulse front) of approx. 1 - 100 times the channel height. Advantageously, the width-to-height ratio is approx. 5:1 - 50:1, typically approx. 30:1 - 5:1.

25 In both of the above-described embodiments, the reaction chamber enclosing the substrate is particularly advantageously designed to have the chamber walls disposed close to the substrate being processed. The inner top wall of the chamber is advantageously aligned parallel to the substrate top surface. In fact as noted earlier, the inner top wall of the chamber may be formed by another substrate.  
30

Minimization of the gas volume in the apparatus improves the utilization efficiency of reactants as a single reaction space can be simultaneously used for growing thin film onto at least two substrates. According to the invention, this arrangement can be implemented by placing the substrates in separate reaction chambers which are stacked vertically or horizontally to provide a reaction chamber pack in which the chambers have common gas flow channels in order to minimize the total volume of the reaction space. The number of vertically or horizontally stacked reaction chambers may be from 2 to 100 and as each of the chambers can be used for processing at least two substrates simultaneously, the total number of thin-film surfaces being processed may be varied in the range of 2 - 200, for instance.

According to a particularly advantageous embodiment, the apparatus according to the invention comprises vertically or horizontally stacked planar elements, whereby said elements have recesses/grooves corresponding to the reaction chambers and gas flow channels machined to them and at least a number of said elements is mutually identical. The edge areas of the planar elements are provided with round, or alternatively, oblong notches or openings extending through the planar element and forming said gas flow channels of said reaction space when said planar elements are stacked vertically or horizontally in order to form a reaction chamber pack. The number of the round openings on the reactant inflow side is advantageously one per each reactant group, which in practice means two openings. The number of oblong openings required on the inflow side is only one.

The center parts of the planar elements can be provided with areas recessed from the plane of the element so that the recesses are connected at their reactant inflow and outflow sides, respectively, to said notches or openings. The recessed areas form the reaction chamber of the reaction space, or a portion thereof. The flow connections between the recessed areas and the gas flow channels act as restrictions to the gas flows. The recessed areas of the element may be made so deep as to extend through the entire thickness of the planar element leaving the center of

the element open. Advantageously, the inner edges of the recessed areas conform along at least two opposite sides of the recess to the edges of the substrates, thus permitting the location of the substrates in the recesses. When desired, the inner edges of the recesses can be provided with brackets serving to support the  
5 substrate. In the latter case the broad walls of the reaction chamber pack are formed by substrates placed into the center openings of the planar elements, whereby the substrates may be aligned so as to, e.g., have the substrate top sides facing each other.

10 The above-described apparatus construction details make it possible to reduce the weight of the reaction space and minimize the number of components in the system. By arranging the reaction space to comprise vertically or horizontally stacked reaction spaces, the length of the gas inflow and outflow channels, respectively, can be reduced. This is particularly true for the latter case in which the substrates  
15 themselves serve as the broad walls of the reaction chambers.

The invention provides significant benefits over prior-art ALE reactors. Accordingly, the pulsing concept of the starting materials based on never having two or more different starting material species transported in the system simultaneously  
20 effectively isolates the starting materials from each other thus preventing their premature mutual reactions. Should such reactions occur in the gas phase, CVD thin film growth would result, whereby the reactor deviates from the operating conditions of the ALE process and the reactor cannot be called an ALE reactor any more. In fact, the CVD thin film growth condition in conventional ALE reactors  
25 often causes the formation of the detrimental microparticle dust/spalling.

According to the invention, the risk of CVD thin film growth is eliminated thereby yielding true surface-controlled thin film growth, and thus, excellent ALE process qualities; in fact, the apparatus according to the invention realizes the  
30 separate reaction steps characterizing a true ALE process.

The minimized surface areas and volumes also minimize the amount of extra thin film growth in the piping, whereby the rate of dust/spall formation and need for cleaning are reduced. The small gas volume with optimized fluid dynamics speeds the through-flow of gases and improves the purging of gases participating in the reactions, which is evidenced as faster process rate and improved thin film quality.

The evacuation steps and possible complementing step of flushing with an inactive gas also contribute to the efficient removal of molecules adsorbed on the inner walls of the system and thus lessen the tendency of the molecules to react with the molecule species of the successive reactant pulse.

In the following the invention will be examined in greater detail with reference to the appended drawings in which

Figure 1 is a longitudinally sectioned side view of a simplified structure for the reaction chamber pack in a first embodiment according to the invention, and Figure 2 is a longitudinally sectioned side view of a simplified structure for the reaction space construction in a second embodiment according to the invention.

Referring to Fig. 1, the apparatus construction shown therein comprises a reaction space, or a reaction chamber pack 1, assembled from mutually identical, stacked planar elements 10, in which pack the gas flow channels 7, 4 and reaction chambers 13 are formed by openings and notches made to the planar elements. The apparatus is shown to incorporate four reaction chambers 13 having placed therein eight substrates 12 onto which thin films are grown using the ALE process. Reference numeral 3 denotes the connection of the reaction chamber pack to a pipe communicating with the inlet of a pump. The connection communicates with the outflow channel 4 of vapor-phase reaction products and excess reactants, whereby the outflow channel acts as collecting manifold for the outflows from the reaction chambers. Correspondingly, reference numeral 2 denotes the inflow

opening for vapor-phase reactants, whereby said inflow opening further communicates with the reactant inflow channel 7.

5 The planar elements are provided with an encircling suction groove 5 for collecting any gas leaks. The suction groove communicates with the outflow channel 4. The purpose of the suction groove is to avoid the access of external contamination into the reaction space and to prevent reactants from leaking outside the reaction space. Thence, the groove acts as an isolating gas seal for the reaction space.

10 When stacking the planar elements, between each two superimposed elements is placed an intermediate plate 6 suited for controlling the restriction of the gas flow by setting the cross section of the inlet slit 8 from the inflow channel 7 into the reaction chamber 13 and the cross section of the outlet slit, that is, gas flow restriction, from the reaction chamber to the outflow channel 4.

15 The upper half of the uppermost reaction chamber acts as the top plate 9 of the reaction chamber pack, and correspondingly, the lower half of the lowermost reaction chamber acts as the bottom plate 11, which is mounted onto a support base 17. Between said top plate and bottom plate are stacked three mutually  
20 identical planar elements 10. Each planar element forms firstly in combination with the substrate 13 the wall between two adjacently stacked reaction chambers, and secondly, in combination with the intermediate plates 6 and other auxiliary plates, forms the inflow and outflow channels 7, 4. The number of the planar elements may be varied in the range 0 - 100 pcs.

25 The inflow/outflow channels 7, 4 and the reaction chambers are shaped to have longitudinally a narrow, oblong cross section to facilitate a "flattened" gas flow and minimize the volume of the reaction space.

30 In the embodiment illustrated in Fig. 1, the vapor-phase reactant pulses of different reactant groups are fed alternately into the inflow channel 7. Prior to the



feed, the gas inflow pulses are homogenized with an inactive gas flow in the inflow channel 7 or before. In the inflow channel, shown longitudinally sectioned in the diagram, the vapor-phase reactant pulse travels flattened into a planar shape which proceeds along the channel with a defined leading front. The flow front has  
5 a width equal to the that of the substrate, which is approx. 10 - 30 cm, for instance, while the thickness of the front is approx. 1 - 3 cm.

The flow travelling in the inflow channel is distributed evenly between the in-parallel stacked reaction chambers 13 by dimensioning the reaction space with its  
10 gas flow restrictions so that the flow conductance of the inflow channel 7 is much higher than the flow conductance via the reaction chambers 13. The flow path through each reaction chamber must have a conductance which is equivalent (equal) to that of the gas paths via the other chambers. Then the pressure and flow rate is balanced between the individual reaction chambers, and thence, the thin  
15 film growth rate is also equal in the separate chambers. Inside the reaction chamber 13, the flow pattern is equalized by virtue of the narrow suction slit 14 formed to the outflow end of the reaction chamber. The suction slit may be formed by either a single, contiguous slit or a plurality of small, parallel slits which in the exit direction of the flow is/are preceded by the large-volume  
20 reaction chamber 13 having a larger relative flow conductance than that of the slit(s). Then, the gas flow tends to exit via the slit(s) in an equally distributed pattern. In the reaction chamber 13 this is manifested as an equalized cross-directional pressure gradient of the leading edge of the propagating gas pulse meaning an equalized propagating gas front. In tests (with reduced reactant  
25 dosing) the gas front has been found to have an extremely straight contour.

Ensuring the equalized cross-directional outflow pattern of gas front is extremely important, because the gas molecules tend to travel toward the direction of lowest pressure (most effective suction), whereby the straight gas front will be distorted if  
30 subjected to a nonhomogeneous suction. Moreover, a homogeneous suction effect will rectify a gas front distorted due to other possible reasons.

After the exit of the vapor-phase reactants from the reaction chamber and particularly the reaction space, their possible mixing how complete whatsoever will not cause harm to the thin film being grown.

5 Referring to Fig. 2, an embodiment slightly different from that described above is shown. The legend of reference numerals in the diagram is as follows:

- 21. Reaction chamber pack
- 22. Inflow duct opening for starting materials of group A
- 10 23. Inflow duct opening for starting materials of group B
- 24. Connection for pipe communicating with suction inlet of pump
- 25. Collecting outflow channel for outflow slits from in-parallel stacked reaction chambers
- 26. Suction groove encircling the planar element for collection of possible gas
- 15 leaks, whereby the suction groove communicates with the collecting outflow channel.
- 27. Intermediate plate serving for setting of outflow slit height, that is, gas flow restriction. In addition to its function as setting the outflow restriction, the intermediate plate forms a baffle separating the different starting material groups
- 20 at the inflow side.
- 28. Inflow channel for starting materials of group B
- 29. Inflow channel for starting materials of group A
- 30. Inflow channel serving for the distribution of the starting material flows to the paralleled reaction chambers
- 25 31. Top plate and one half of the uppermost reaction chamber
- 32. 0-100 pcs. identical planar elements. Each planar element in combination with the substrate forms the separating wall between two superimposed reaction chambers as well as the inflow and outflow channels in combination with the intermediate plates and the other auxiliary plates.
- 30 33. Bottom plate and one half of the lowermost reaction chamber
- 34. Uppermost plate of support base

- 35. Middle plate of support has
- 36. Lowermost plate of support base
- 37. Substrates
- 38. Reaction chamber
- 5 39. Restriction for gas flow leaving the substrate.

The embodiment shown in Fig. 2 is used in the same fashion as that illustrated in Fig. 1. However, this construction differs from first embodiment in that the starting materials of different reactant groups are taken along their own inflow  
10 channels up to the inflow slits of the reaction chambers. Hence, the reaction chamber pack is assembled onto such a support base plate set 34 - 36 which after their stacking provide individual flow ducts 22, 23 for the reactants of the different starting material groups. Similarly, the reactants travel in their individual inflow channels 28, 29 at the side of the reaction chamber pack.

15 The gases are fed from the inflow channels 28, 29 separated by the baffles 27 formed by the intermediate plates, whereby the height of the reaction chamber is dimensioned so that diffusion performs efficient intermixing of the flows entering from the different channels. While diffusion is a too slow mixing method to be  
20 used in the width direction of the flattened gas flow pattern, it performs well in the height direction. Thus, when the reactant is fed from one inflow channel 28, for instance, the inactive gas is fed from the other channel 29. When impinging on the baffles, the reactant and inactive gas flows, respectively, are flattened assuming a planar flow pattern, whereby they are homogenized during their  
25 intermixing in the inflow slit of the reaction chamber.

The inflow ducts 22, 23 and the inflow channels 28, 29 may have a circular cross section, for instance, and the reactant gas flows are spread into a fanned and flattened shape only at the baffles.

Analogously with the first embodiment, securing the equalized cross-directional outflow pattern of the gas front is extremely important.

Still referring to Fig. 2, it must be noted that the positions of the inflow channels 28 and 29 are slightly displaced for clarity. In a practical embodiment, these inflow channels are arranged in parallel, that is, adjacent in the lateral direction, whereby their infeced openings into the reaction chamber will be located at the same distance from the substrate.

#### 10 Example

The following example describes the design principles for the pump of the apparatus shown in Fig. 1 and the interval between the successive vapor-phase reactant pulses, respectively, that make the apparatus perform in accordance with the invention:

Substrate size	300 x 300 mm <sup>2</sup>
Number of substrates	10 pcs.
Number of reaction chambers	5 pcs.
20 Spacing between substrates	4 mm
Total volume of reaction chambers	$5 \times 300 \times 300 \times 4 \text{ mm}^3 = 18,000 \text{ cm}^3$
Dimensions/volume of inflow channels	$300 \times 10 \times 100 \text{ mm} = 300 \text{ cm}^3$
Dimensions/volume of outflow channels	$300 \times 10 \times 100 \text{ mm} = 300 \text{ cm}^3$
25 Total volume	$18,600 \text{ cm}^3$ , or approx. 19 l.

The pump capacity is selected as  $360 \text{ m}^3/\text{h}$ , or  $360 \times 1000/3600 \text{ (l/s)} = 100 \text{ l/s}$   
Hence, the above-calculated total gas volume can be evacuated with a pump so dimensioned in approx. 0.2 s.

A pump with the above-calculated capacity requires a pumping line with an inner diameter of 76 mm, having a volume per length unit of  $\pi \times 0.38 \times 0.38 \times 10 \text{ dm}^3 = 4.07 \text{ l/min}$ , which means that if the length of the pumping line from the reaction chamber pack to the outlet connection of the apparatus is 1 m, for instance, its  
5 evacuation takes an extra time of 0.04 s.

Accordingly, the interval between the reactant pulses in the above example is selected as approx. 0.25 s, which is a sufficient time for one-time evacuation of the entire gas volume of the apparatus during the interval between two successive  
10 reactant pulses. By extending the interval between the pulses to 1 s, for instance, the total gas volume can be evacuated approx. 4 times. Here, an inactive gas may advantageously be introduced to the reaction space during the evacuation.

**Claims:**

1. A method for growing a thin film onto a substrate, in which method a substrate placed in a reaction space (1; 21) is subjected to alternately repeated surface reactions of at least two vapor-phase reactants for the purpose of forming a thin film, said method comprising
- feeding said reactants in the form of vapor-phase pulses repeatedly and alternately, each reactant separately from its own source, into said reaction space (1; 21), and
  - bringing said vapor-phase reactants to react with the surface of the substrate for the purpose of forming a solid-state thin film compound on said substrate,
- characterized in that
- the gas volume of said reaction space is evacuated essentially totally between two successive vapor-phase reactant pulses.
2. A method as defined in claim 1, characterized in that said gas volume of said reaction space (1; 21) is evacuated at least twice, advantageously at least 3 - 10 times during the interval between said vapor-phase reactant pulses.
3. A method as defined in claim 1 or 2, characterized in that said gas volume of said reaction space (1; 21) is evacuated so that the residual components of the preceding vapor-phase reactant pulse remaining in the reaction space are at a level of less than 1 %, advantageously less than 1 ‰, prior to the inflow of the successive vapor-phase pulse.
4. A method as defined in any of foregoing claims 1 - 3, characterized in that an inactive gas is fed into said reaction space (1; 21) simultaneously as the reaction space is being evacuated from the residues of the latest vapor-phase reactant pulse.

5. A method as defined in claim 4, c h a r a c t e r i z e d in that to said reaction space is connected a pump (3; 24) having a volumetric capacity which during the interval between two successive vapor-phase reactant pulses is appreciably greater than the gas volume of the reaction space.

5

6. A method as defined in any foregoing claim, c h a r a c t e r i z e d in that each reactant is fed into said reaction space via a separate inflow path (22, 29; 23, 28) in order to minimize the gas volume to be evacuated from the reaction space.

10

7. A method as defined in any foregoing claim, c h a r a c t e r i z e d in that each vapor-phase reactant pulse is mixed with said inactive gas flow prior to its entry into said reaction space.

15

8. A method as defined in claim 1, in which method a reaction space is employed comprising a reaction chamber (13; 38) into which said substrate can be placed and further comprising gas flow channels (7, 8, 14 and 4; 22, 23, 28, 29, 25 and 24) communicating with said reaction chamber, said gas flow channels being suited for the inflow of said vapor-phase reactant pulses into said reaction chamber and, correspondingly, for the outflow of the nonreacted components of said reactant pulses from said reaction chamber, c h a r a c t e r i z e d in that at least a portion of said gas flow channels are provided with a narrow, oblong cross section in order to minimize the volume of said reaction space.

20

9. A method as defined in claim 1 or 8, in which method a reaction space is employed comprising a reaction chamber (13; 38) into which said substrate can be placed and further comprising gas flow channels (7, 8, 14 and 4; 22, 23, 28, 29, 25 and 24) communicating with said reaction chamber, said gas flow channels being suited for the inflow of said vapor-phase reactant pulses into said reaction chamber and, correspondingly, for the outflow of the nonreacted components of said reactant pulses from said reaction chamber, c h a r a c t e r i z e d in that

30

said reaction chamber (13; 38) is provided with a narrow, oblong cross section in order to minimize the volume of said reaction space.

10. A method as defined in claim 9, c h a r a c t e r i z e d in that said vapor-phase reactant pulses are fed via gas flow channels (7, 8, 14 and 4; 22, 23, 28, 29, 25 and 24) having a narrow, oblong cross section in order to form at least essentially planar pulses of vapor-phase reactant and to improve the intermixing of the vapor-phase reactant flow with a carrier gas flow.
11. A method as defined in claim 9, c h a r a c t e r i z e d in that said vapor-phase pulses of each reactant group are fed via their individual inflow channels (22, 29; 23, 28) directly into the reaction chamber, wherein the vapor-phase pulse is allowed to intermix with a carrier gas flow prior to bringing the reactant into contact with the substrate.
12. A method as defined in claim 1, c h a r a c t e r i z e d in that said vapor-phase reactant pulses are fed in an at least essentially laminar flow into said reaction chamber.
13. An apparatus for growing thin films onto a substrate by subjecting the substrate to alternately repeated surface reactions of vapor-phase reactants for the purpose of forming a solid-state thin film on the substrate, said apparatus comprising
- a reaction space (13; 38) into which the substrate can be placed,
  - inflow channels (7; 22, 29, 23, 38) communicating with said reaction space, said channels being suited for feeding the reactants employed in a thin-film growth process in the form of vapor-phase pulses into said reaction space, and
  - reactant outflow channels (4; 25) communicating with said reaction space, said channels being suited for the outflow of reaction products and excess amounts of reactants from said reaction space,



c h a r a c t e r i z e d in that

- the outflow channels (4; 25) are provided with a connection (3; 24) to a pump capable of evacuating said reaction space to a vacuum and said pump having a volumetric capacity which during the interval between two successive vapor-phase reactant pulses is greater than the gas volume of the reaction space.

14. An apparatus as defined in claim 13, c h a r a c t e r i z e d in that said pump has a volumetric capacity which during the interval between two successive vapor-phase reactant pulses is capable of evacuating at least twice the gas volume of the reaction space.

15. An apparatus as defined in claim 13 or 14, said apparatus comprising a reaction chamber (13; 38) into which the substrate can be placed and further comprising gas flow channels (7, 8, 14 and 4; 22, 23, 28, 29, 25 and 24) communicating with said reaction chamber, said gas flow channels being suited for the inflow of said vapor-phase reactant pulses into said reaction chamber and, correspondingly, for the outflow of the reaction products of said thin-film growth process and the excess amounts of said reactant pulses from said reaction chamber, c h a r a c t e r i z e d in that at least a portion of said gas flow channels are provided with a narrow, oblong cross section in order to minimize the volume of said reaction space.

16. An apparatus as defined in claim 15, c h a r a c t e r i z e d in that said reaction chamber (13; 38) is provided with a narrow, oblong cross section in order to minimize the volume of said reaction space.

**1/2**

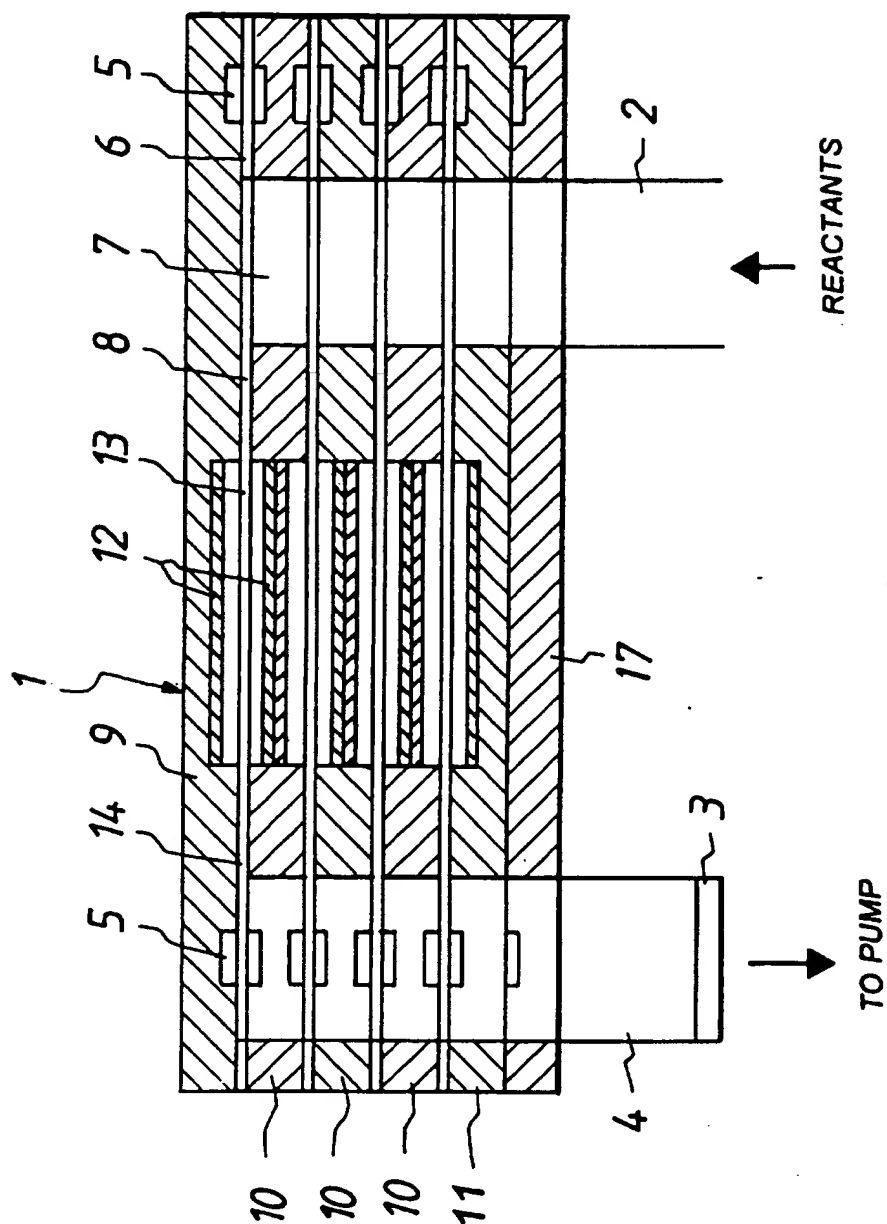


Fig. 1

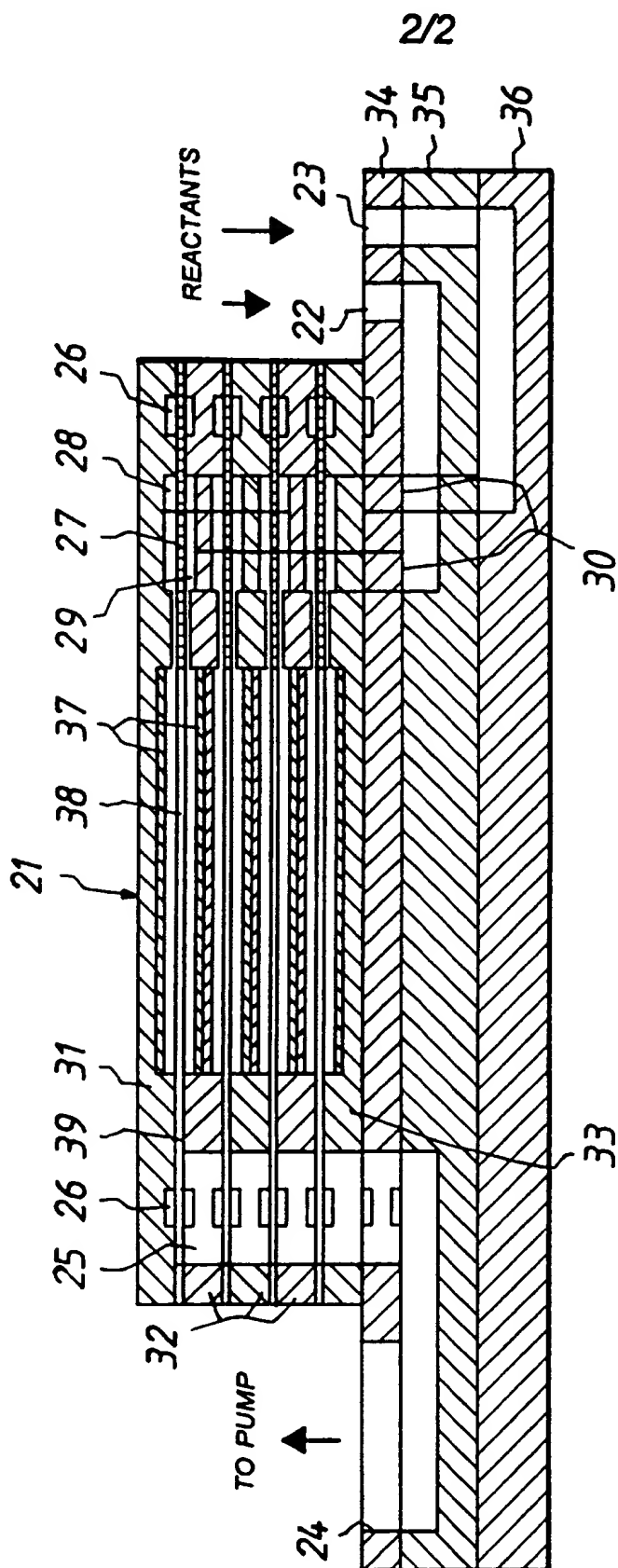


Fig. 2

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI 95/00658

## A. CLASSIFICATION OF SUBJECT MATTER

IPC6: C23C 16/44, C23C 16/00, C30B 25/02

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: C23C, C30B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4993357 A (CHRISTOPH SCHOLZ), 19 February 1991 (19.02.91), column 2, line 9 - line 19; column 3, line 3 - line 61; column 6, line 25 - line 35, column 7, line 6 - line 9	1-5,13,14
Y	figure 2 --	6-12,15,16
X	US 4058430 A (TUOMO SUNTOLA ET AL), 15 November 1977 (15.11.77), column 4, line 34 - line 42; column 5, line 47 - column 6, line 8, figures 6,7, abstract --	1-3,6,8, 13-15
Y	EP 0015390 A1 (OY LOHJA AB), 17 Sept 1980 (17.09.80), page 6, line 5 - page 9, line 31, figures 4,7,11, abstract --	6-12,15,16



Further documents are listed in the continuation of Box C.



See patent family annex.

## \* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

26 April 1996

Date of mailing of the international search report

29 -04- 1996

Name and mailing address of the ISA/  
Swedish Patent Office  
Box 5055, S-102 42 STOCKHOLM  
Facsimile No. +46 8 666 02 86

Authorized officer

Ingrid Grundfelt  
Telephone No. +46 8 782 25 00

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI 95/00658

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0559326 A1 (PIONEER ELECTRONIC CORPORATION ET AL), 8 Sept 1993 (08.09.93), column 4, line 35 - line 39, figure 1  -----	8-12,15,16

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

01/04/96

International application No.

PCT/FI 95/00658

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4993357	19/02/91	DE-A,C- 3743938	13/07/89
		DE-D- 3886023	00/00/00
		EP-A,A,A 0321909	28/06/89
		JP-A- 1264993	23/10/89
US-A- 4058430	15/11/77	AU-B- 505960	06/12/79
		AU-A- 8666275	26/05/77
		BE-A,A- 835906	16/03/76
		CA-A- 1066174	13/11/79
		CH-A- 618469	31/07/80
		DE-A,B,B 2553048	10/06/76
		FR-A,B- 2292517	25/06/76
		GB-A- 1495987	21/12/77
		JP-C- 1147355	26/05/83
		JP-A- 51077589	05/07/76
		JP-B- 57035158	27/07/82
		NL-A- 7513284	01/06/76
		SE-B,C- 393967	31/05/77
		SE-B,C- 401986	12/06/78
		SE-A- 7513336	31/05/76
EP-A1- 0015390	17/09/80	SE-T3- 0015390	
		AU-B,B- 535151	08/03/84
		AU-A- 5578680	04/09/80
		CA-A- 1166937	08/05/84
		JP-C- 1299997	31/01/86
		JP-A- 55130896	11/10/80
		JP-B- 60021955	30/05/85
		SU-A,A- 1085510	07/04/84
EP-A1- 0559326	08/09/93	US-A- 4413022	01/11/83
EP-A1- 0559326	08/09/93	JP-A- 6216030	05/08/94
		US-A- 5370738	06/12/94